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**DEPARTMENT OF MATHEMATICS,  
STATISTICS, AND COMPUTER SCIENCE**

**FINAL TECHNICAL STATUS REPORT**

**FOR**

**CONTRACT AFOSR 85-0347**

**Department of Mathematics, Statistics,  
and Computer Science  
University of Illinois at Chicago  
Chicago, Illinois 60680**

**October 31, 1989**

**Klaus J. Miescke  
Professor  
and  
Principal Investigator**

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**Technical Status Report**  
**of AFOSR Supported Research under Research Contract**  
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KLAUS J. MIESCKE  
Department of Mathematics, Statistics, and Computer Science  
University of Illinois at Chicago  
Chicago, Illinois 60680

October 1989

## SUMMARY

This is the fourth annual and final scientific report on the progress and outlook of the research activities in the areas of optimum selection procedures in multi-stage screening, reliability, and time series analysis problems, sponsored by the United States Air Force Office of Scientific Research under the contract AFOSR 85-0347, which started on September 30, 1985, continued on October 1, 1987, and ended on September 30, 1989.

## Optimum Selection Procedures in Multi-Stage Screening, Reliability, and Time Series Analysis Problems

This research originated from the area of Ranking and Selection. Its purpose is the development of optimum decision rules which assist in the detection and/or early use of the best of  $k$  available populations, which may be components, materials, treatments, or techniques. Special emphasis is given to applications of realistic problems which arise especially in the area of Statistical Reliability. Potential Air Force applications are improvement of the quality and performance of military equipments.

### 1. Two-Stage Selection Procedures with Screening at the First Stage.

Such procedures are highly desirable in practice, since only those populations which perform well at the first stage are further examined at the second stage. This helps to restrict sampling and examination of inferior populations. Thus it saves already money during the phase of comparisons of materials and equipments.

**Weibull Populations.** Type II-censoring is used here at both stages, where sampling from each population stops at Stage 1 after the  $q$ -th failure occurs, and where sampling from the retained populations at Stage 2 stops after an  $r$ -th failure occurs.

The number of units tested may be different for the  $k$  populations. At the second stage, the intact units of the retained populations may be augmented by additional numbers of units of the respective types, where these numbers may again differ from population to population.

Optimum rules of this type are derived, aspects of proper choices of  $q$  and  $r$  are discussed, and the *least favorable parameter configuration* of that version which has a fixed subset size at Stage 1 is found for its implementation under the *indifference zone approach*.

These results, which provide rules ready to be used by experimenters, which are new to the area of Statistical Reliability, and which will stimulate further research in this direction in the future, are published in [1], which is jointly with S.S. Gupta.

**Normal Populations.** In a Bayesian approach, the optimum subset of fixed size is derived to maximize the best performance at the second stage. The setting is highly nonsymmetric, as the usual assumptions of equal sample sizes, equal variances, or equal priors are not made. The determination of a realistic set of priors is thoroughly demonstrated. These results are

not only a novelty to the area of marketing but also to all fields of empirical studies where the best-performing of several competitors has to be found. This work has been published in [2], which is jointly with C.M. Ehrman and A. Krieger.

**Binomial Populations.** In the same spirit, a two-stage procedure for binomial populations has been derived. In a general cost-benefit approach, which fits into various frameworks of applications, the optimum predetermined number of competing binomial populations to be tested at the first stage has been found for the purpose of using the most promising competitor later, at the second stage, on a much larger scale. This research [4], which is jointly with C.M. Ehrman, will appear soon.

## 2. One-Stage Selection Procedures for Nonsymmetric Models.

For a long time, it has been taken for granted that the *natural selection rules*, which are optimum in symmetric (*decreasing in transposition*, DT) models, are also suitable under lack of symmetry due to different sample sizes, variances, etc. Thorough investigations in this direction, which is of great statistical importance, constitute a major part of our research efforts. The results and future extensions are outlined below.

**Normal Populations.** Suppose there are  $k$  normal populations with equal variances, where the problem is to find that one which has the largest mean. After one has drawn  $k$  samples, the *natural decision rule* is to select the population which yields the largest sample mean. If the sample sizes were in fact equal, this decision would be optimum, as it is well known. However, little was known up to now about the performance of this *natural rule* in the case of unequal sample sizes.

It could be demonstrated now that this rule is no longer minimax under 0-1 loss, and that it performs poorly, more precisely "worse than at random", if the population means are close together. Several of the findings turn out to be rather counter-intuitive. Alternative rules have been derived, mainly in the Bayes approach, where emphasis is given to robustness with respect to the priors. The results, which will stimulate further work by other researchers in this direction, have been presented in an invited paper at the **Fourth Purdue Symposium on Statistical Decision Theory and Related Topics** in June 1986. They are published in [3] and are jointly with S.S. Gupta.

A very important extension of selection procedures is to include estimation of the mean of the selected population. Most of the results in the literature are based on the assumption that the natural selection rule is used. However, this is not appropriate if the sample sizes are unequal. In a decision theoretic approach, using an additive loss for selection and estimation,

new optimum procedures have been found jointly with S.S. Gupta. It can be expected that this work will spark further research in the future because of the need of experimenters to know what has been actually selected. The results are reported in [11] and are submitted for publication.

**Binomial Populations.** After the normal case, it has been quite natural to consider next the analogous situation of  $k$  binomial populations. Finding the highest success probability based on Bernoulli sequences of different lengths is certainly a problem of great statistical importance. Joint work in this area with former Ph.D. candidate M.M. Abughalous has been completed recently. Some results, including minimaxity, are similar to the ones found in the normal case, but by far not all. This indicates that only some of the findings can be generalized to models based on exponential families. This work is presented in [6]. It is jointly with M.M. Abughalous and has been published.

**Multivariate Normal Populations.** Similar investigations for the multivariate normal model with a nonsymmetric covariance structure have been made by M.M. Abughalous. In his thorough examination of various types of covariance matrices, he has shown among other very interesting facts that surprisingly, the natural rule can be minimax under 0-1 loss for some special forms of non-exchangeable normal distributions. His results are reported in [8], which are submitted for publication.

Thanks to the generous support of his thesis work by the AFOSR during the summer of 1988, M.M. Abughalous could complete his Ph.D. without any teaching assignment.

### 3. Reliability and Replacement Policies.

Reliability and replacement policies are research areas which are in certain parts very close to selection topics. Thus techniques from the latter could be applied successfully to problems in these areas. Most of our research results outlined in this report are in one way or another useful toward reliability applications and thus would fit as well into this section.

**Lognormal Populations.** One-stage selection of the best of  $k$  lognormal populations, which differ only in one certain parameter, can be treated within the model of normal populations, as long as two-parameter lognormal distributions are considered. However, finding the three-parameter lognormal population with the largest guaranteed lifelength is much more difficult. An optimum selection procedure could be derived which is based on the L-statistic with the smallest asymptotic variance. In this joint work with S.S. Gupta, it is demonstrated that selection should not always be made through "natural" estimators such



as the sample mean or median. These results are reported in [5] and have been published recently.

**Weibull Populations.** Comparing the breaking strengths of  $k$  materials to find the most reliable type is an important problem. For dental composites, accelerated life time models with Weibull baseline distributions, which are suitable for other experimental environments as well, have been fitted to data of aged materials. These results, which are jointly with J.L. Drummond, are presented in [9] and are submitted for publication.

**Optimum Replacements.** Optimum replacement policies during the joint usage of  $k$  competing brands or types of components in a system of  $n$  components have been developed recently by the principal investigator. Under the assumption of exponentially distributed failure times, a rule has been found which minimizes the posterior expected waiting time for the next failure in the system, using the growing experience from the past. Moreover, other situations have been studied where the information from the past is only partially known. The case of  $k = 2$  has been treated also with Markov chain techniques to optimize the probability of absorption at the better of the two terminal stages. This work is reported in [7]. It has been an invited paper at the **IMS Meeting at Boston** in March 1988, and it has been submitted for publication.

#### **4. Trend Analysis in Time Series.**

Besides many different interesting problems, which are naturally arising in the course of our research efforts outlined above, such as the joint work with M.N. Musa on mixtures of three normal populations, which is reported in [10] and submitted for publication, one special topic has and is presently investigated: The analysis of nonstationary periodic time series.

Nonparametric techniques to detect periods in time series, as well as those to locate special trend properties in time series of known periods, are under current investigation. Theoretical studies and computer simulation programs have led to some interesting partial results which are planned to be completed in the near future.

One project, which is jointly with C. Eastman, is focussing on the circadian rhythm in man. Hereby, subjects are forced from a 24 hour daily cycle to longer or shorter cycles, and permanent body temperature measurements are used to determine the extent of adjustment to the new cycles. This, combined with methods designed to assist the switch to the new cycles, will lead to treatments which will help to alleviate stress caused by shift work and air travel time lags.

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